

Current Procedures for Assessment of BDR in Helicopters

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ABSTRACT

This paper will discuss the current US Army Battle Damage Assessment and Repair (BDAR) doctrine, with a review of the purpose and employment of current BDAR by aviation units in the field. It will define the key aspects of BDAR and conduct an in-depth review of BDAR assessment per current US Army doctrine. The paper will then examine key personnel responsibilities with regard to effective BDAR, categories of maintenance and repair, and the BDAR timeline, including how BDAR “triage” is used in the field. With current doctrine established a comparison and contrast of how actual BDAR is being conducted and what mechanisms have been established to increase aircraft readiness, repair, and availability will be analyzed. Several examples of various actual BDAR field repairs will be presented for review and discussion. The paper discusses the ever evolving BDAR organization that is intertwined with forward deployed engineering support, from the start of Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF) to its current in-theater configuration.

1.0 BATTLE DAMAGE ASSESSMENT AND REPAIR (BDAR) AN INTRODUCTION

New tactical air vehicles are normally designed to be ballistically survivable on the modern battlefield by incorporating active and passive signature reduction and ballistic tolerance features. A large percentage of these air vehicles return from combat missions with various levels of combat damage. Maximum air vehicle availability is essential during combat operations; therefore, quick assessment and repair of the damages are necessary. To assess damage and determine reusable parts and components, some additional tools and equipment are required, as well as additional training for aviation unit, direct and general support level maintenance personnel.

The types of threats confronting the US Army rotorcraft in combat include kinetic energy projectiles, explosive projectiles, and air-to-air and surface-to-air missiles with explosive warheads. In addition to the threats the rotorcraft might encounter in flight, they are exposed to damage by bombs and artillery while on the ground. Threat studies and tests have shown that modern rotorcraft are highly survivable against the kinetic energy hits, moderately survivable against one or two small explosive hits, and minimally survivable against a large explosive or single air-to-air or surface-to-air missile hit. Being the most survivable of the threats, kinetic energy hits cause most of the damage that maintenance personnel will encounter. Some of these projectiles are the armor-piercing incendiary (API) type and contain a thermally active nose filler. Upon impact, this filler is activated as the projectile penetrates the exterior of the target. This gives the projectile a fire-starting capability in the presence of flammable materials.

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Damage mechanisms for the explosive threats include fragments, blast, overpressure, fire, and other secondary damage. A BDAR program should be established to provide an expeditious means of combat damage assessment for deferment or repair. The BDAR program should include special techniques, tools, equipment, and procedures to be used by aviation units under combat conditions. The primary function is to provide quick-fix material and techniques to increase air vehicle availability under an intense combat environment. The program should be composed of required hardware and documentation to provide the capability to inspect, assess, and repair the air vehicle. Support documentation includes inspection procedures, damage assessment criteria, serviceability criteria, expedient repair procedures, cannibalization techniques, and assessment and repair handbooks. Hardware includes damage assessment aids (such as die penetrant kits, micrometers, etc.), repair tools, ground support equipment, and repair material.

The current assessment process includes evaluating the extent of damage sustained and determining whether deferment is feasible. Scheduled and unscheduled maintenance and minor battle damage, except for necessary lubrication, servicing, and preoperational checks, may be deferred. Unscheduled maintenance, such as the repair of systems and subsystems that have adequate redundancy or are not critical to mission accomplishment, can be deferred if safety of flight is not significantly degraded. Relaxed inspection criteria for repair and air vehicle performance should also be evaluated and defined.

For example, the number of broken strands in flight control cables, leak rates of hydraulic systems, and oil consumption rates of engines and gearboxes should be redefined. The BDAR process also includes procedures to perform rapid battle damage repair where necessary within the constraints imposed by time, manpower, material, and operational requirements. The primary purpose of rapid battle damage repair is to restore sufficient strength and serviceability to the air vehicle to permit it to fly additional operational missions or to permit partial mission capability. Demonstrations of typical repairs should be made to determine whether the structural integrity, time constraints, tools, and maintenance personnel meet defined requirements.

The types of structure and the material forms should be considered. Primary structures, such as beams, frames, longerons, and fittings, are essential to airworthiness because airworthiness of the entire airframe depends on the distribution of loads through the individual structural elements. When combat damage reduces the strength, stiffness, or stability of these elements, a decision on repair methods must be made. This critical decision should be based on a judgment of whether redistribution of the load may degrade flight safety or adversely affect flying qualities. Sheet stock and extruded materials that are not preformed are needed for most repairs. Typical materials used in modern air vehicles include aluminium, steel, titanium, magnesium, and composites. These materials may be worked and formed into airframe structures, such as brackets, ribs, bulkheads, extrusions, honeycombs, or sandwiched assemblies.

Consideration should also be given to the use of installed instrumentation and monitoring devices to make reusability decisions in the field after a combat incident or resulting crash. Possible devices include but are not limited to accelerometers; maximum "G" recorders; debris monitors; engine torque, temperature, and RPM monitors; and heat sensitive paint and paper indicators. Knowledge of these damage or crash parameters helps expedite deferment or repair assessment. Measures used to quantify BDAR qualification may include time to repair (TTR) at each maintenance level and effectiveness of the repair, which is expressed as the number of life units the repair lasts.

2.0 PURPOSE

The purpose of Battle Damage Assessment and Repair (BDAR) is to quickly return the disabled helicopter to the operational commander by expediently fixing, bypassing, or jury-rigging components to restore the

minimum essential systems required for the support of the specific combat mission or for self-recovery. These repairs will be temporary and may not restore full performance capability. Standard repairs will be completed as soon as practical.

3.0 BDAR

During the first few days of combat maximum aircraft availability is essential. Aircraft will sustain varying degrees of damage during combat operations. The damage must be assessed and repaired as quickly as possible. Maximum availability must be maintained for further sorties. In addition to the combat damage, aircraft will have higher component failure rates because of increased flying hours and higher stress levels. Aircraft combat maintenance battle-damage repair (ACM/BDR) is an operational concept for maintaining aircraft at a high level of readiness in combat. Peacetime maintenance procedures and methods must be modified to achieve this. One method will be to defer all but the most essential maintenance needed for the next scheduled mission. They will often be flown with nonessential components damaged, inoperative, or missing. The Army currently has Battle Damage Assessment and Repair manuals for the following classes of helicopters: UH-60, AH-64A/D, CH-47D and OH-58 A/C/D; and, every one of these Battle Damage manuals opens with these two caveats:

- “BDAR fixes shall be used only in combat or for training at the discretion of the commander, in either case damages shall be repaired by standard procedures as soon as practicable.” The manual talks about “the Command” however the Level of command is not specified in Manual, based on general field experiences; it is normally at Brigade with a shift move down possibly to Battalion, with a Standard Operating Procedure (SOP) for direction.
- Repairs are made using interim techniques, off-the-shelf standard hardware (not necessarily aircraft related) and without concern for appearance.

4.0 BATTLEFIELD DAMAGE DEFINITIONS

It will be helpful to discuss some of the common terminology and definition used in BDAR:

- a. Battle Damage. Any incident such as combat damage, random failures, operator errors, accidents, and wear out failures which occur on the battlefield and which prevent the helicopter from accomplishing its mission.
- b. Repair or Fix. Any expedient action that returns a damaged part or assembly to a full or an acceptably degraded operating condition, including:
 - Short cuts in parts removal or installation.
 - Installation of components from other equipment that can be modified to fit or interchange with components on the damaged equipment.
 - Repair using parts that serve a noncritical function elsewhere on the same equipment for the purpose of restoring a critical function.
 - Bypassing of noncritical components in order to restore basic functional capability.
 - Expeditious cannibalization procedures.
 - Fabrication of parts from kits or readily available materials.
 - Temporary substitute fix.
 - Use of substitute materials.



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c. Damage Assessment. A procedure to rapidly determine what is damaged, whether it is repairable, what assets are required to make the repair, who can do the repair (e.g., crew, maintenance team or maintenance support team), and where the repair should be made. The assessment procedure includes the following steps.

- Determine if the repair can be deferred, or if it must be done.
- Isolate the damaged areas and components.
- Determine which components must be fixed.
- Prescribe fixes.
- Determine if parts or components, materials, and tools are available.
- Estimate the manpower and skill required.
- Estimate the total time (clock hours) required to make the repair.
- Establish the priority of the fixes.
- Decide where the fix shall be performed.
- Decide if recovery or evacuation is necessary and to what location.

d. Fully Mission Capable (FMC). The helicopter can perform all its combat missions. To be FMC, the helicopter must be complete and fully operable with no faults listed in the aircraft inspection and maintenance record as prescribed in the Army's DA PAM 738-751.

e. Combat Capable. Equipment meets the minimum functional combat capability requirements.

f. Combat Emergency Capable. The equipment meets the needs for specific tactical missions; however, all systems are not functional. Also, additional damage due to the nature of an expedient repair may occur to the equipment if it is used. The commander must decide if these limitations are acceptable for that specific emergency situation.

g. Cannibalization or Controlled Exchange. Throughout the BDAR manual, cannibalization and controlled exchange are used interchangeably meaning the removal of an item of materiel from one piece of equipment for immediate use in another. Generally the rules for cannibalization/ controlled exchange provided in US Army Technical Manual, TM 1-1500-328-23, as modified by local authority, will prevail.

h. Evacuation. A combat service support function which involves the movement of recovered helicopters from a main supply route, maintenance collection point, or maintenance activity to higher categories of maintenance. The material may be returned to the user, to the supply system for reissue, or to property disposal activities.

i. Recovery. The retrieval of immobile, inoperative, or abandoned helicopter from the battlefield or immediate vicinity, and its movement to a maintenance collection point, the main supply route, or a maintenance activity for disposition, repair, or evacuation.

j. Self-Recovery. The ability of a battle damaged helicopter to retrieve itself (fly out) from a battlefield environment. It usually will involve flying with degraded flight status and with restrictions and limitations placed on performance characteristics such as limitations placed on weight, airspeed, engine torque, and other characteristics. In BDAR repairs, the limitations recommended should be followed. Emergency flight procedure in respective Technical Manual (TM) should be further consulted.

- k. Maintenance Collection Point. A point operated by AVIM unit for the collection of equipment for repair.
- l. Maintenance Support Team (MST). A team of AVIM mechanics and technical specialist who are trained in assessing battlefield damage and field repair procedures.
- m. Maintenance Team (MT). Helicopter crew chief or AVUM mechanics/technicians who are trained in assessing battlefield damage and field repair procedures.

5.0 BDAR ASSESSMENT

According to the US Army's BDAR doctrine, "Assessors will be trained to identify and assess damage and failed aircraft subsystems. They will learn isolation and repair methods and procedures and serviceability standards." Who are these BDAR assessors? Battle-damage assessors must have a minimum aviation skill equivalent to a technical inspector and Assessors must have successfully completed training in battle-damage assessment. Additional assessors may be aircraft maintenance officers and technicians who have completed the Aircraft Maintenance Officer Course. They must also be assigned to aircraft maintenance positions. The Aviation Maintenance Company's (AMC) primary purpose is to support the momentum of offensive operations. The AMC will perform BDAR and the AVUM or unit level and determine the priority of these repairs. Additionally, all Aviation Unit Logistics Assistance Representatives (LAR's) are trained in BDAR and provide technical assistance and recommendations for BDAR repairs.

5.1 Assessor Responsibilities

The assessors' primary responsibilities are to evaluate damage and determine repairs needed to quickly return aircraft to operational service. Resources must not be wasted on aircraft which cannot be repaired within specified time limits. They must be able to isolate damage, determine repair methods and procedures, and learn the serviceability standards, or mission limits. Their assessment is used to determine which aircraft need expedient repair, which can be flown with only minor attention, and which cannot be repaired in time to meet combat requirements. The objective is to return the maximum number of aircraft to a flyable condition. It may be determined that aircraft cannot be made flyable within time and/or manpower constraints. In this case they may be source of repair parts. Assessors will determine the requirements for and sequence of repairs. They establish an estimated time to complete repairs by skill. They also coordinate with the maintenance authority to establish an estimated time of availability.

- AVUM Level. At the level, the assessor may seek assistance from specialist on various aircraft systems. However, the assessor is responsible for the assessment and recommendations given to the maintenance authority. The maintenance authority determines the priority for repairs.
- Field Recovery Site. At the field recovery site, the assessor evaluates aircraft damage. He also recommends repairs to the maintenance authority. The maintenance authority decides what repairs can be made under the immediate tactical situation.
- Restrictions. The assessor will assist the maintenance authority in determining what restrictions must be placed on the aircraft because of BDAR.
- Repair Priority. When the assessment is complete, the maintenance authority determines the priority in which aircraft will be repaired based on the assessors' reports.

"BDR techniques are limited only by Safety considerations, Experience and skill of repairmen, and component or substitute availability." In Peacetime, flight safety requires restoring damaged structure to its original condition. Consideration is given to strength, corrosion protection, and cosmetic appearance. Repairs



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are devised by the aircraft engineering authority where expert advice is available and time is available to evaluate. During combat, damage and repairs will be quite different. Time will be of the essence and the engineering authority and advice will be limited. Under combat conditions, BDAR may be performed on helicopters which are in flight or which are under power while on the ground. While some of these BDAR actions may require waiving of safety precautions, the cautions to protect personnel life should not be overlooked. Other similar precautions may be waived at the discretion of the commander. BDAR fixes may be required in a chemically toxic environment or under other adverse battlefield conditions with severe limitations in personnel, facilities, equipment, and materials. Performance of repair tasks may be necessary while wearing protective gear.

5.2 Maintenance Categories

What is desired and needed is sufficient strength to maintain operation flying is the primary concern of the assessment and repair. In some aircraft, extensive damage may require little work, i.e. non structural member, in others the smallest crack could be catastrophic. For example: When a damaged aircraft is flown it can be assumed that some structural strength is still present. However this does not mean sufficient strength is available to do mission with added weight of fuel and armament. An assessors must look at all these factors to determine capability for the next sortie. The damage inspection is used to locate and classify damage in three steps: inspecting the damage, labeling the damage, submitting the BDAR report.

- Scheduled Maintenance. There are no scheduled maintenance and inspections. However, necessary lubrication, servicing; and operational checks will not be deferred. When conditions permit, the "overflown" inspections will be completed. When expedient repairs are made on the aircraft or repair of damage is deferred, to ensure flight safety or mission accomplishment, it may be necessary to schedule inspections at subsequent flight hour intervals. Scheduled battle damage inspections of this type will not be deferred.
- Unscheduled Maintenance. Repair of systems and subsystems which are not critical to mission accomplishment, may be deferred unless they might cause further damage. Items may be deferred even if it places operational limitations on the aircraft, as long as the restricted aircraft can accomplish designated missions and can contribute to the battle. Deferment of repairs for a one-time flight to a higher maintenance level, or for self-recovery from a combat area, is highly desirable. This eliminates the need for another aircraft to accomplish the recovery, or the loss of the aircraft if recovery is not available. The maintenance officer or assessor will make the decision based on an analysis of the overall situation and airworthiness of the aircraft.
- Assessment. Aircraft which have battle damage will be inspected and classified by a damage assessor using a method similar to the medical concept of "triage." Following assessment some aircraft will be returned to service immediately through deferment. Other aircraft will be repaired using approved battle damage repair techniques. On the average, a repair action at the AVUM level should take 4 hours to perform and the maximum should be no more than 8 hours; whereas, at the AVIM level, the repair action should take no longer than 24 hours. These aircraft will be set aside and repaired as manpower and parts become available. Other aircraft will be repaired using approved battle damage repair techniques. Repairs are made using interim techniques, off-the-shelf standard hardware (not necessarily aircraft related) and without concern for appearance. Aircraft that have sustained major battle damage so that BDAR is not practical may be either ground-recovered or air-evacuated to a facility with required repair resources, cannibalized (or controlled exchange) for spare parts, or destroyed in place to prevent enemy capture.

5.3 BDAR Time Requirements

The time line for accomplishment of BDAR is crucial to returning maximum assets to the battlefield in a quick and timely manner. Current US Army BDAR doctrine follows the following timeline guidance:

- Covering Force: <180 minutes, only 45 minutes is for repair
- Main Battle Area: <180 minutes, only 45 minutes is for repair
- Rear Area: <217 minutes, only 109 minutes is for repair
- This includes
- Assessing combat damage
- Deferring maintenance
- Perform battle damage repair
- Cannibalization & controlled exchange/substitution

Damage limits have been established to fly an aircraft “as is” in certain cases. These requirements are:

- Type 1
 - 100 flight hours or 30 days is typical
 - Full flight envelope
 - Inspected after every flight
- Type 2
 - One time flight
 - Limited flight envelope
 - Apache example
 - Maximum airspeed of 100 knots
 - Maximum vertical load factor of 2.0
 - Black Hawk example
 - Maximum airspeed 80 knots
 - Maximum vertical load factor of 1.5
 - Maximum of 3 flight hours
 - Gradual pedal movements not to exceed 50% of available travel from trim positions
 - Landing at level attitude; soft touchdown from hover

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5.4 BDAR Triage

The triage assessment chart (see Figure 1) guides the assessor through the helicopter's capability so that all capabilities are evaluated. If a fault is found, the chart will direct the assessor to the chapter for the functional group which contains the fault. The BDAR assessment procedure will refer to a guide fix in the respective aircrafts BDAR TM, a standard field TM repair if it is feasible, or a higher AVIM level of repair if extent of damage, time constraint, tooling requirements, repair part or material, and any other necessary requirements are only available at a higher level of maintenance.

The triage assessment chart is dedicated to a "quick look aircraft zone" inspection. This technique is intended to quickly identify critical damage which is not repairable or would require extensive repair (high manhours) times. Each "aircraft zone" contains several subsystems, each having critical components (mainly airframe structure and aircraft wiring). The quick look visual "aircraft zone" inspection will ensure a successful aircraft triage. A sample "triage" flowchart diagram is shown below.

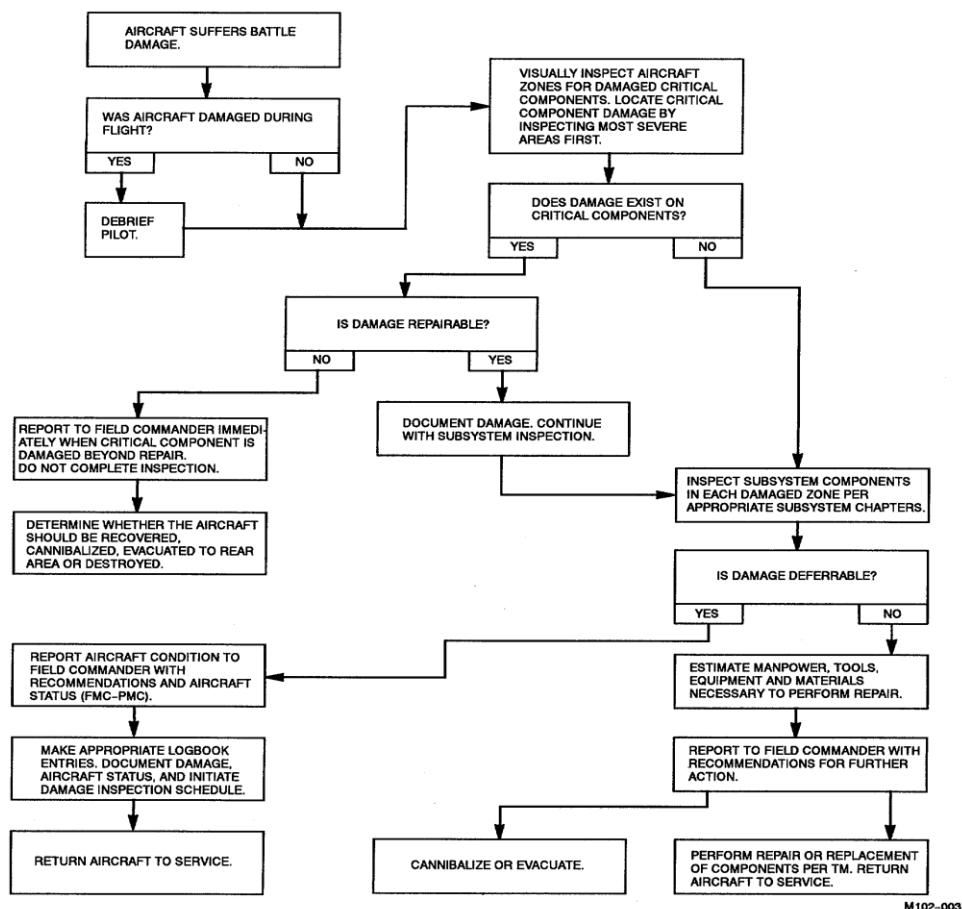


Figure 1: Sample BDAR Triage Chart

5.5 BDAR Evaluation and Repairs: Using the Book

Ballistic damage to a wire harness cannot be classified as critical or non-critical. Function of the equipment will determine the condition of the aircraft. Wire harness damage can be repaired, but in severe cases troubleshooting and repair can expend hundreds of man-hours. Typically, a wire harness will be routed through all areas of a helicopter and interconnect several components and subsystems. The complexity of the wire harness repair is dependent on the number of components and subsystems involved. When damage exists, the assessor needs to decide and recommend a deferrable, repairable or non-repairable action. Man-hours, materials, tools and equipment will need to be estimated. In certain cases, the repair man-hours can be reduced by limiting the repair to essential equipment, permitting the aircraft to be used at a reduced capability.

Deferrable, repairable or non-repairable actions are decided on a per aircraft basis taking into account type/amount of damage and need for aircraft inspection with the most severely damaged portion of the aircraft to the scarcely damaged areas. Visually inspect the aircraft zone structure and related subsystems for critically damaged components. BDAR TM's have special tables and charts to properly identify critical components unable to tolerate damage without immediate repair. When non-repairable or extensive repair time damage is found, triage inspection is halted and the findings to the appropriate level of authority for aircraft disposition. When quick look visual "aircraft zone" inspection is completed, the assessor will proceed with detailed subsystem assessment and operational inspection following the triage assessment chart.

Damage evaluation's purpose is determine whether damage to structure capability has degraded it below a minimum acceptable (i.e. point of failure). All damage is scheduled for repair, it is the timeframe that is in question. The Commander defers noncritical airframe damage, individual members are classified as serviceable or failed. These can be deferred for up to 100 hours. Deferability assessment goal is to determine whether an aircraft with battle damage structural members must be repaired or can safely flown without repair. (i.e. hourly, with daily inspection, etc.) Warning associated with deferment, "deferring Battle damage to primary structure will reduce the aircraft's ability to withstand further projectile damage and in many cases it will also decrease survivability. Performing combat missions with unrepairs damage may increase the risk to aircraft and crew if additional damage is suffered. Chapter 2 of the Battle Damage Technical Manuals discusses and establishes the limits on airframe damage. Again , the maximum deferral of repair/inspection is 100 hours.

As part of battle damage inspection, the area of damage needs to be cleaned, to find cracks, imbedded particles, etc. Locating all entrance and exit wounds is a important first step. Use the pilot post flight/mission debrief to help identify possible areas. Armor Piecing (AP) and Armor Piercing Incendiary (API) leave smooth holes, round or oblong in shape depending on angle of impact. Delay fuse High Explosive Incendiary (HEI), will probably penetrate airframe and exit, similar to API. Proximity and point detonation-create large irregular wounds accompanied by deformation and tearing of metal and numerous fragmentation holes. Bombs,/mortars/artillery rounds will result in irregular holes of various sizes. The fragmentation pattern will involve many individual penetrators and the complications produced by explosive blast and overpressure makes determining path of fragment difficult. It is crucial to locate all exit wounds, missing exit wounds indicate Foreign Object Damage (FOD) in aircraft and projectile / shrapnel might have struck a structural member and become imbedded.

Critical areas to inspect when doing BDAR inspections are structural changes and cracks. Buckling, misalignment, crippling are all indicators of possible structural damage. For cracks, inspections where the projectile or penetrator made contact. Blast damage and pressure from explosions may also be a source and cause of cracking. Damaged members may result in increased loads on other airframe components which



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must be taken into account. Discoloration of material is an indicator to watch for. If the structural member is subjected to temperatures of 300 degrees Fahrenheit for 30 seconds or less, it is generally considered to be insignificant to the structural member. Intense heat on the other hand may reduce the temper and strength. Eddy current test are available for conductivity test to determine if material properties have changed.

Damage evaluation is used to determine if battle damaged structural members are serviceable or failed. Classified as failed if they exceed certain limits. Also considered failed if continued service would increase it to that limit in a very short time frame. Limits are based on preserving enough strength in the structure to support all loads that might be sustained by the aircraft in combat. Damage to each member must be evaluated and measured unless obvious failure. For primary structural members the limits are given in terms of size and spacing of damage. Secondary members are evaluated in terms of net area loss.

In labeling and reporting the damage, the BDAR TM calls for the measure of the damage after smoothing and cleaning up of the damaged area. This is to ensure an accurate measurement is obtained, measured down to 1/10th of an inch. As the BDAR manual states the damage includes all cracks radiating from the projectile damage, whether a hole or imbedded material. If damage goes to fastener hole, include the hole as part of width and length of damage. Distance between areas should be either 5X or 10X depending on component, again as specified in manual.

Examples of BDAR repairs in the field:

5.1.1 AH-64 Apache BDAR Field Repairs

Referring to Figures 2 & 3:

Damage: Small arms bullet hit Left Hand Engine Nacelle at Frame Station (FS) 219.81 causing hole bullet continued on through the engine nacelle work platform frame assembly at FS 231, severing frame assembly and causing shrapnel to puncture the skin at FS 240. The bullet continued on severing the frame assembly at FS 242 causing a hole in the frame. Bullet impacted the IPS blower duct frame assembly at the primary exhaust nozzle putting a hole in it. The bullet then entered the secondary exhaust nozzle fairing at FS 280 and exited the fairing at FS 290. Both holes had were approx. 3" X 3". The bullet then went through the outboard secondary exhaust nozzle at FS 292.

BDAR: Skin damage repaired with 2" X 2" patch of .032" 2024T3 AL. Frame assembly damage repaired using .040" T3 AL doublers. IPS blower frame assembly was not repaired along with the 2 holes in the secondary exhaust nozzle fairing. Outboard secondary exhaust nozzle was replaced.

Damage: Rocket Propelled Grenade (RPG) punctured left panel L175 at FS 178, Water Line (WL) 126 causing a hole. Round impacted the 30mm spike accumulator at FS 179 WL 129 destroying the mounts and dislodging the accumulator. The accumulator hit the frame assembly at FS 182 causing a 3" X 1.5" hole in the frame assembly. The RPG round and accumulator continued out the left L194 panel causing a hole in the panel of 4" X 6". Both parts hit the left hand wing between the #2 and #3 wing ribs at Left Butt Line (LBL) 41. Damage to wing unknown.

Repair: Hole in bottom of panel L175 was not repaired. Mounts for 30mm spike accumulator repaired by AVIM sheet metal. Spike accumulator was replaced along with the hydraulic lines that were damaged. Frame assembly at FS 182 was repaired using .040" T3 AL doubler, panel L194 replaced and the left wing was replaced.



Figure 2: Apache Battle Damage Example

Damage: Small arms bullet punctured the outer skin on the underside of the Right Hand (RH) engine nacelle at FS 254, WL 164, Right BL (RBL) 30 putting a 0.3" X 0.3" hole in the skin. Bullet continued on through the APU oil sump and lodged itself inside the APU.

Repair: The APU was replaced. The hole in the skin has not been patched.

Damage: Bullet entered B60 panel at FS 70, WL 104, LBL 4 causing a 0.3" X 0.3" hole in panel, continuing on and severed 5 wires in wiring harness W211 and destroyed the hard mount for the Co-Pilot Gunner's lateral LVDT.

Repair: Hole in B60 panel not repaired. Wiring harness repaired by ARMT. Mount for LVDT replaced with .040" T3 AL, and LVDT was replaced.

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Figure 3: Apache Battle Damage Example, Close Up

5.1.2 AH-64 Apache BDAR Field Repairs

Referring to Figure 4:

Damage: Small arms round entered left side exhaust fairing at the center of outboard side. Round continued through nacelle canted frame at FS 284.5, LBL 40.25. This hole was approx. 0.35" x 0.35". Bullet then hit upper outboard nacelle longeron at FS 282.1, LBL 40.5. This hole was approx. 0.5" x 0.7". Round continued and entered nacelle work platform at FS 251.5, LBL 38, creating a 1.7" x 1.1" hole. Round exited nacelle door at FS 264.5 - 260.5, LBL 36, making a 3" x 1" hole.

Repair: Exhaust fairing was patched and filled. Damage to nacelle canted frame and longeron was filled, cleaned and deferred. Nacelle platform was repaired using a 2½" x 2½" inch patch of .032" T3 AL. Nacelle door was also patched with 4" x 2" .032" T3 AL patch.

Damage: Small arms round entered wing 3 inches aft of the number 1 wing stinger at approx LBL 70, creating a 0.35" x 0.7" oblong hole. Round fragmented leaving 3 dents on leading edge approx 1.5", 2.65", & 3.85" forward of the forward spar. All these dents were located between aft rib LBL 78 and forward rib LBL 66. The round exited through the skin 4.6" forward of the forward wing spar, between the same ribs as dents.

Repair: Extent of internal wing damage yet to be determined. Entrance hole in wing was patched with a 3" x 3" .032" T3 AL patch and the exit hole was filled and patched with 4" x 3" .032" T3 AL patch.

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Figure 4: Apache Battle Damage Example Two

5.1.3 OH-58D Kiowa BDAR Field Repairs

Referring to Figure 5:



Figure 5: OH-58D Kiowa Battle Damage Example

Damage: Small arms fire resulted in one hole through a blade. Minor damage on the top side (not pictured). Another hole thru the belly and fuel cell with slight leakage and one hole through the Tail Rotor Gear Box fitting. The aircraft was able to return to base with some vibration.

Repair: Repair of this aircraft consisted of tailboom that came from another crash damaged aircraft (cannibalization/controlled exchange). All holes were patched in accordance with standard repair practices at the AVIM level.



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5.1.4 AH-64D Apache Tailboom BDAR Field Repairs

Referring to Figures 6 - 9:

Damage: This aircraft was flown approximately 30 hours in this condition. During phase maintenance inspection (PMI), it was discovered that the aircraft had in fact, suffered battle damage to the tailboom at frame 496.0, sectional zone location, 2L stringer as seen in Figure 6. The bullet entered through the right side of the tailboom, exiting on the left side impacting the 2L stringer. Other than skin damage there was no other structural damage to the right side of the tailboom. After initial damage assessment, the area was "cleaned up", as shown in Figure 7, to facilitate evaluation of best repair procedure. The on-site Boeing Contractor Field Service Representative (CFSR) developed a repair procedure that was implemented.



Figure 6: AH-64D Apache Tailboom Battle Damage

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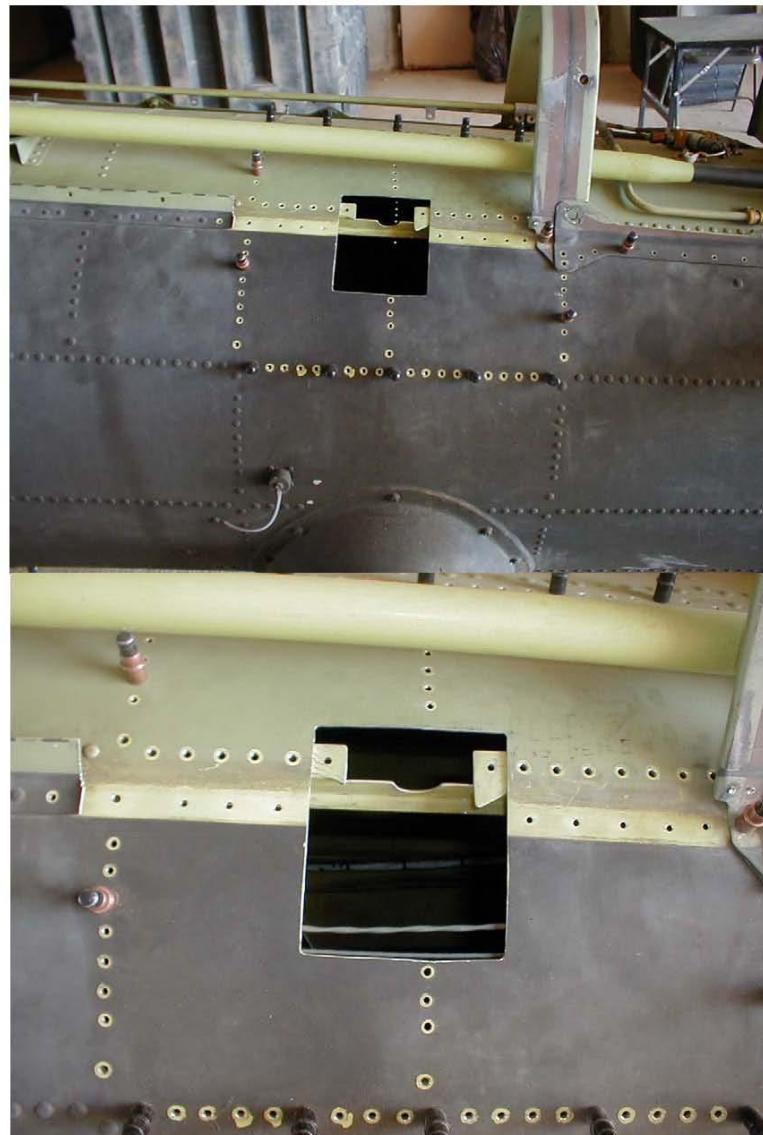


Figure 7: AH-64D Apache Tailboom Battle Damage, Cleaned Up

Repair: The repair was a standard, TM 1-1500-204-23 (series) type repair using standard sheet metal practices. The damaged section of the frame flange was removed but NOT the web, only the top flange. See crosshatch on left and black colored section in Figure 8. An L Angle was fabricated from .040: 7075T6 AL, and riveted in picking up 3 fasteners in undamaged portion of frame. Spacer was fabricated from 7075T6 AL as required for proper shim and fitment.

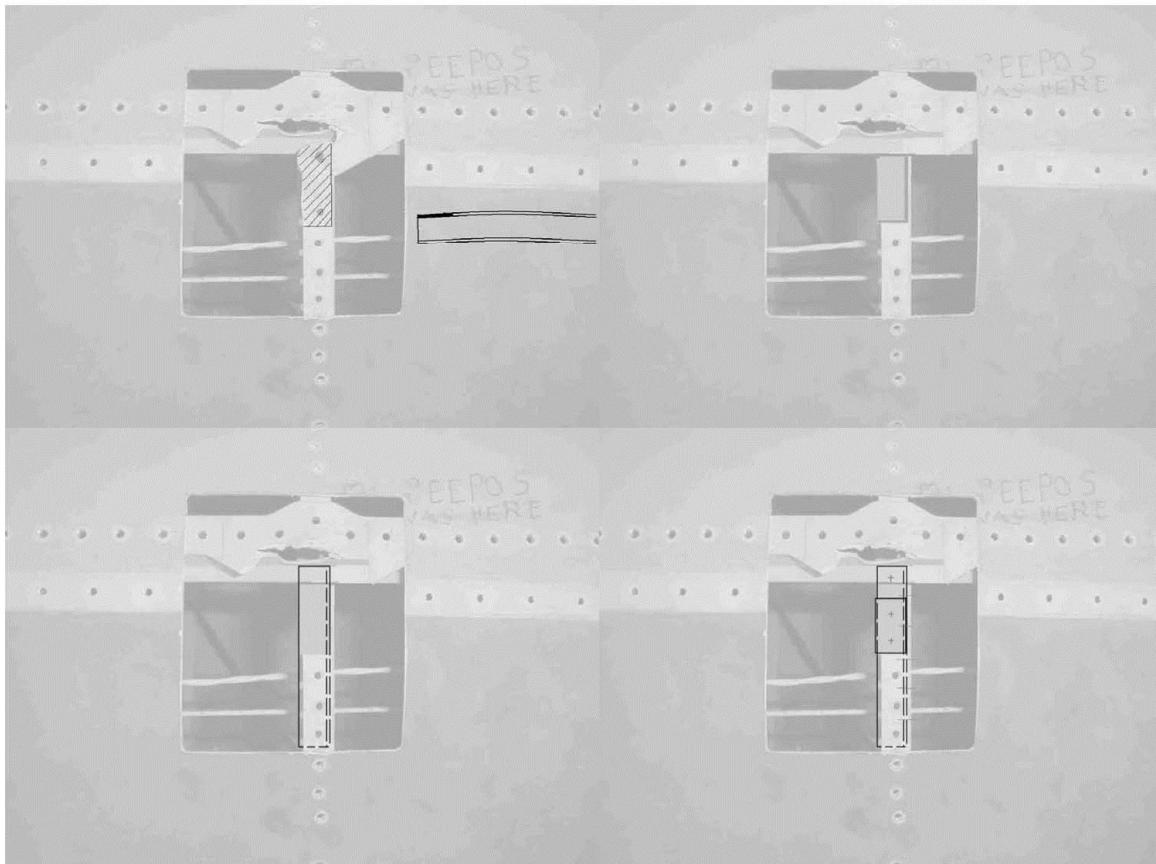


Figure 8: AH-64D Tailboom Battle Damage Example, Filler

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Then a section repair angle was fabricated from 7075T6 AL, same thickness as the damaged stringer. If present material is not available on site, bend in the T0 condition, and heat treat to T6. Angle must extend for at least 4 fasteners either side of skin cut out. Angle was then installed under and on right side of damaged stringer. Filler was fabricated to sit on top of repair angle and fill removed damaged area of stringer. Filler had to be wide enough to pick up the one fastener to the right of the stringer and at least two fasteners to the left of the stringer. Material was again will be 7075T6 AL or T0 AL treated to T6. Filler was contoured to skin curvature, except directly over the repair angle. Skin filler was fabricated from 2024T3 AL, at the same thickness as skin, leaving at least 0.050" clearance between cut-out and filler edges to prevent chafing. Skin doubler was fabricated from 2024T3 AL, one gauge thicker and picked up at least two fasteners all the way around the outside of the skin cut out. See Figure 9 below:

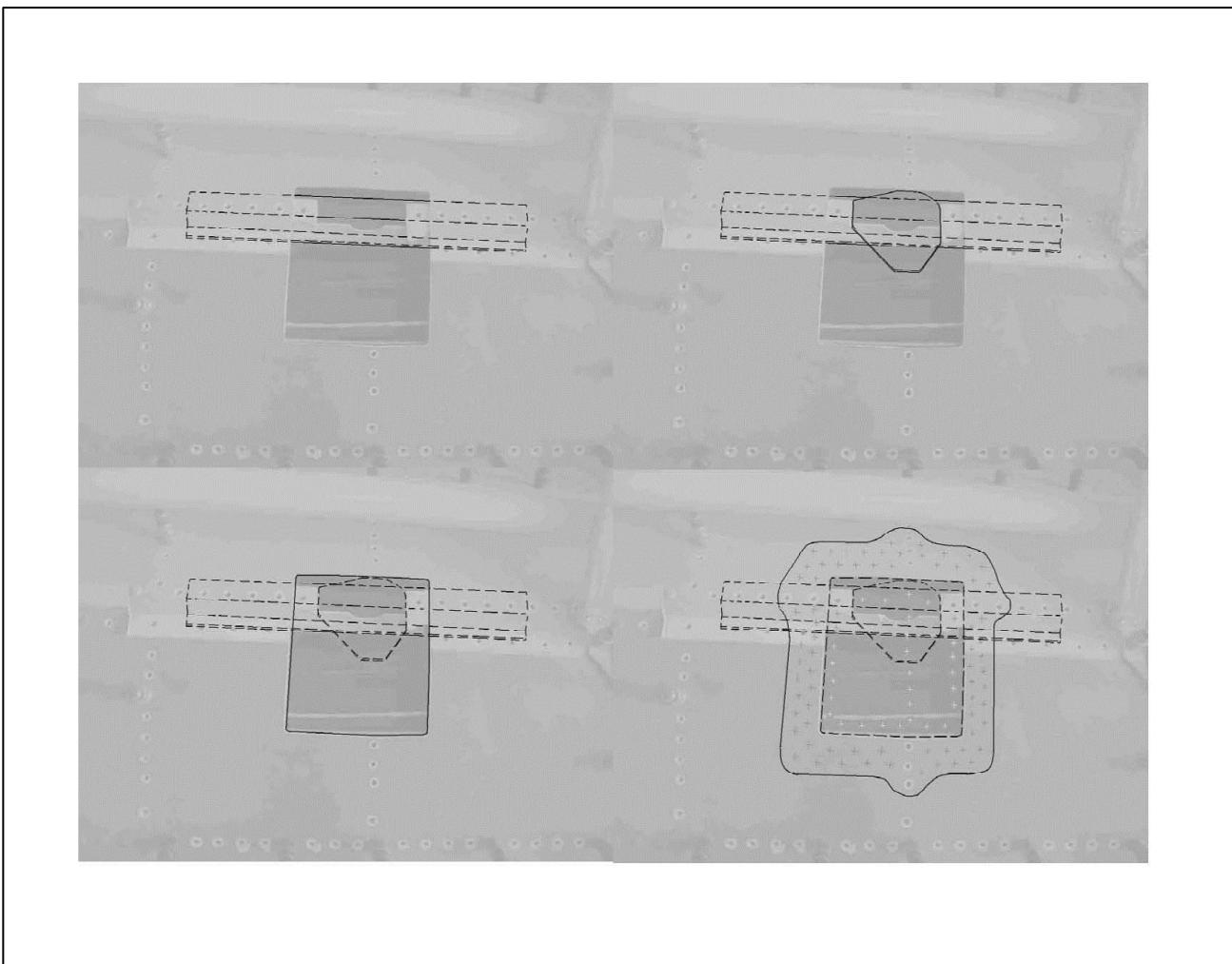


Figure 9: AH-64D Tailboom Battle Damage Example, Doubler

6.0 STANDARD DOCTRINE VERSUS CURRENT PROCEDURES & DOCTRINE ADAPTATION

The US Army BDAR TM's were written under the auspice of a high intensity or full out war scenario. With current operations low intensity conflict level or in Operations Other than War (OOTW), the BDAR doctrine must be, and has been, modified or adapted to the current environment in the respective theater of operations. Since the Army's airworthiness program, Army Regulation (AR) 70-62, covers the entire aircraft life cycle, including maintenance, actions taken during aircraft maintenance (depot and field) and repair, including BDAR, can adversely affect airworthiness. The Army had to adapt to this new type of warfighter environment to maintain both combat readiness and aircraft airworthiness. By having Aviation Engineering Directorate (AED) Liaison Engineers (LE) teaming with Contractor Field Service Representatives (CFSR) and Logistic Assistance Representatives (LAR), the unit is provided with the most lean and responsive level of field support achievable. Deviations from existing maintenance publications must be approved by AED LE's, and cannot be authorized by contractor CFSRs or the AMCOM LAR's. By having an on-site LE, they can provide dedicated, timely support, and continue to provide airworthiness support, even in BDAR situations.

6.1 Liaison Engineer in Theater of Operations Support

To assist with operation Enduring freedom (OEF) and Operation Iraqi Freedom (OIF) accomplish BDAR and other maintenance and engineering tasks, a Liaison Engineer (LE) has been stationed in each in theater since 2003. Originally stationed in Arifjan, Kuwait, when the 1109th AVCRAD deployed and established the TAMP in February 2003. From May 2004 to the present, an LE has been stationed in Balad, Iraq. The Engineering station in Iraq (OIF) is located in Balad, Iraq, just 70 km North of Baghdad. Balad is a joint service air base with a squadron of F-16s and an Army aviation brigade, including ground support assets and ground combat forces. Beginning in February 2008, similarly, an LE was stationed in Afghanistan (OEF) in Bagram. This was later increased to two LE's in each theater of operations. These LE's provide forward engineering capability and support to effect repairs that might normally require support back in CONUS. Over 50 US Army Aviation Engineering Directorate (AED). Aerospace Engineers deployed since February 2003 to date. Some of the key functions these deployed LE's vitally provide are:

- Serve as on-site AED airworthiness Liaison Engineer
- Empowered to provide on-the-spot decisions on a wide variety of aircraft maintenance issues
- Call-back to AED (Redstone & Corpus Christi Army Depot) as necessary for technical guidance.
- Provide units with Maintenance Engineering Calls (MECs) to authorize nonstandard repairs, to address field exigencies, and to resolve crash and battle damage repairs.
- AED LE's have completed over 2000 MECs supporting OIF/OEF in FY09 alone (see Figure 10).

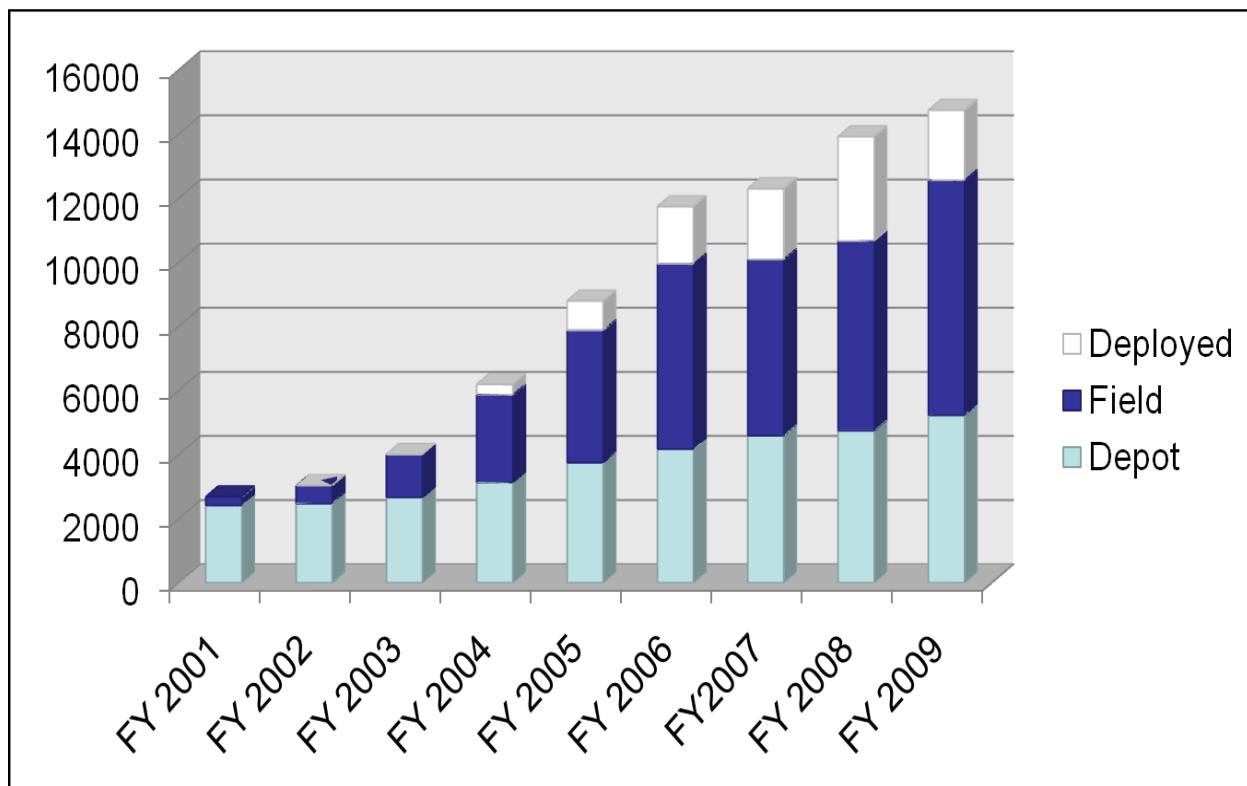


Figure 10: MEC Breakdown during the OEF/OIF years.

6.2 Theater Aviation Maintenance Program (TAMP) Mission and Organization

The Theater Aviation Maintenance Program or TAMP mission is to provide organizational, intermediate, and limited depot-level maintenance of aircraft and their engines and components; implement modification work orders; provide technical assistance to aviation units; establish special repair activities; provide supply and personnel support services; and control Army aviation intensively managed items. TAMP Provides Forward Presence for Maintenance & Limited Depot Repair

The National Guard's Aviation Classification Repair Activity Depots or AVCRAD's have been instrumental in providing aviation maintenance support for Operations Iraqi Freedom (OIF) and Enduring Freedom (OEF). The Army National Guard has four AVCRADs. They are located in Connecticut, Mississippi, Missouri, and California. These units are designed either to operate from a fixed base at their home stations or to fall in on Corpus Christi Army Depot (CCAD), Texas, to augment that depot's workforce.

Filling the TAMP role, the 1109th AVCRAD in Groton, Connecticut, deployed to OIF in 2003 and established depot operations in a warehouse in Kuwait. The 1107th AVCRAD in Springfield, Missouri, took over operation of the warehouse from the 1109th in 2004 and converted the warehouse into a series of shops that produced depot-repaired components in support of the NMP. The 1106th AVCRAD in Fresno, California, deployed to Kuwait in 2005 to support OIF 2004-06 and expanded the operation to provide support to OEF

AVCRAD's deployed to the Southwest Asia area of operations support aviation reception, staging, onward movement, and integration (RSO&I) and the National Maintenance Program (NMP) for Army Materiel Command (AMC) Southwest Asia. These AVCRADs also are the Coalition Forces Land Component Command (CFLCC) reserve aviation maintenance resource. The AVCRAD's are responsible for limited depot aircraft maintenance, component repair, pass-back aviation intermediate maintenance (AVIM), and operation of a supply support activity (SSA). (Pass-back AVIM is repair that cannot be performed by the units designated to provide it because they have an excessive amount of work requests, lack personnel with the required training and expertise, or lack the proper tools and equipment.)

Within a month of its arrival in Kuwait, the 1106th AVCRAD sent a mission analysis team to Iraq to determine the warfighters' forward depot operations needs. The key problems identified by the team were difficulty in moving maintenance contact teams and components within the theater and in communicating requirements from units in Iraq to the AVCRAD in Kuwait. When an aircraft suffers battle damage or is damaged in a hard landing, for example, it must be repaired and returned to the fight as quickly as possible. Repairing a damaged aircraft requires parts, special tools, and skilled, technically adept personnel. To meet these needs, the 1106th AVCRAD developed the forward operations cell (FOC) concept of support. The FOC provided depot expertise forward to communicate requirements, positioned a movement control team (MCT) in Iraq to manage parts flow, stationed depot teams and tools forward to reduce response time, and served as a forward command and control node for the AVCRAD commanders. The FOC was able to respond to customer requirements within minutes or hours instead of days, as had been the case when the AVCRAD had to respond from Kuwait.

The AVCRAD component repair mission required that unserviceable, repairable components be transported to Kuwait. Often, after receiving a component, the AVCRAD found that it would have to be evacuated to the continental United States (CONUS) for repair. Part of the FOC mission was to reduce the number of components being transported unnecessarily on the hazardous roads of Iraq by placing AVCRAD supply and technical inspectors forward in Iraq to classify unserviceable equipment. Only components that could be repaired by the AVCRAD's shops were shipped to Kuwait. Components that could not be repaired in Kuwait were consolidated and shipped by strategic airlift back to the appropriate CONUS depot.

6.3 RESET Process

The U.S. Army's Aviation RESET Program was established under the direction of the Army Material Command in April 2003 to track and manage the inspection, repair and overhaul of the helicopter fleet deployed in Iraq and Afghanistan. RESET's Mission Definition is to restore aviation equipment to a fully mission capable condition in accordance with AR 700-138 using special technical inspection and repair procedures outlined in Army Technical Bulletins (TBs). Assist Program Managers in fleet configuration control through the application of outstanding Modification Work Orders (MWOS) and perform limited depot repairs.

RESET is not routine scheduled maintenance or depot overhaul. RESET an 100% disassembly of the aircraft and its dynamic components (Engines, Rotor Systems, Drive Trains, Flight Control Systems, etc.). It involves 100% cleaning of all airframe and components and a complete serviceability inspection of all airframe and component elements. The aircrafts entire historical record is reviewed and corrected if necessary. All required Army recommended modifications are completed to the aircraft and all components are refurbished to 100% or replaced. All outstanding and deferred maintenance actions are completed on the aircraft. RESET corrects discrepancies and damage associated with both BDAR and discovered under A3T/ACE. RESET returns an immediately deployable aircraft to the unit with significantly improved operational availability and safety



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characteristics. The goal of the RESET timeline is to have a new asset ready for deployment within 90 days of induction into the program.

6.4 ACE/ A3T: AIRFRAME CONDITION EVALUATION – ARMY AVIATION ASSESSMENT TEAM

ACE is an annual assessment of the fleet to gather data on the structural condition of the aircraft, like an annual check-up. ACE is required per Army Regulation (AR) 750-1, and is used to determine depot candidacy of aircraft/airframe. A number of aircraft specific predetermined specific inspection locations, called indicators, are evaluated. These indicators are checked for certain defect conditions, such as cracking, or corrosion. The assessment results in a numeric score for every aircraft (the higher the score, the worse the condition of the airframe). The score is the result of adding points assigned to various types of defects identified during the assessment. Scores for each mission design series (MDS) are unique to that series. A numeric score from one MDS cannot be compared to the numeric score of another MDS. Each aircraft's score depends on both the number of defects found, as well as the indicator they are located on. For example, sheet metal defects are usually not as critical as frame defects, so the frame defects typically have a higher scoring weight. The ACE results are then stored in the ACE database, which includes the ACE profile score, defect locations by fuselage station, water line, and butt line, as well as any additional comments made by the evaluators.

ACE data is used to identify candidates for depot repair and to identify symptoms of airframe corrosion, overstress and fatigue data collected during evaluations is stored in the ACE database and is used for technical and logistical analysis. ACE does not replace any regular field maintenance or inspections; ACE does, however, improve overall fleet safety and readiness by targeting aircraft based on need of repair rather than time based inspections. ACE is a management tool as well as an engineering tool. Aircraft that have gone through RESET show lower average scores in subsequent evaluations when compared to non-RESET aircraft. Aircraft that have gone through RECAP showed significantly lower average scores in subsequent evaluations when compared to non-RECAP aircraft.

6.5 AIRCRAFT COMBAT MAINTENANCE /BATTLE DAMAGE REPAIR

The manuals give you a lot of leeway/flexibility, here is where common sense has to play a role. The manuals state “there are no schedule maintenance and inspections” However you still need to do the necessary lubrication, servicing and operational checks will be performed. And when time permits, overflown inspections will be completed. Scheduled battle damage inspections will not be deferred, i.e. if the designated BDAR Point of Contact (POC) has determined a inspection needs to be done every 5/10 hours, whatever he comes up with, those cannot be deferred

Repair of systems and subsystems which are not critical to mission accomplishment many be deferred unless they might cause damage. Items may be deferred even if it places operational limitations (no ESSS ops, restrict use of 30mm), on the aircraft, as long as the restricted aircraft can accomplish its designated missions and can contribute to the battle. Deferment of repairs for a one time flight to a higher maintenance level or for self recovery from a combat area is highly desirable. That eliminates the need for another aircraft to accomplish the recovery, or the long term loss of the aircraft if recovery is not available. The maintenance officer or assessor makes the decision based on analysis of the overall mission and airworthiness of the aircraft.

7.0 LIVE FIRE TRAINING

Prior to any actual firing tests, analyses should be performed by the AC to identify vulnerable components and subsystems and maximize the efficiency of live fire testing. The System Threat Assessment Report/System Threat Assessment (STAR/STA) is the basic threat document defining the threat environment in which the development system should function. If required by the PA, actual live fire tests (LFTs) should be performed on those components with either actual or simulated surrounding structures and components.

Four elements of ballistic survivability testing might be tested by the Government. These elements are armor, ballistic tolerant structure, and components positioning and separation of subsystems, and fuel ballistic protection. Threat projectile, impact location, obliquity, tumble, and striking velocity should be specified in Government test plans, and should be recorded and reported for all firing tests. Another element of LFT, lethality, is primarily related to weapons systems effectiveness testing. Compatibility of armor with typical operators and maintainers should be validated by Government use personnel prior to beginning LFT. Validation is intended to confirm that armor installed in its normal position does not interfere with critical operator and maintainer tasks.

If battle damage assessment and repair (BDAR) is a requirement, such repairs should be validated using LFT assemblies and components to demonstrate specification compliance. Since only vulnerable areas should be tested, measures of the air vehicle airworthiness and mission effectiveness are primarily related to probabilities of suffering a specific type of kill such as attrition, mission abort, or forced landing kills, and may be expressed as the probability of a kill given a hit (PK/H). Instrumentation required to monitor these tests may include video recorders, instruments for monitoring electrical and functional parameters, such as current, torque, and temperatures, and pressure transducers for monitoring transient fluid and blast pressures.

8.0 CONCLUSIONS AND SUMMARY

Battle Damage Assessment and Repair (BDAR) is an ever evolving, ever changing tactic, not unlike other battlefield tactics, that must be continuously adapted to a variable and changing arena. As Robert Burns wrote, "The best-laid plans of mice and men often go awry", so do doctrines and tactics, since every outcome or result cannot have a pre-planned contingency. The process of BDAR is no exception to this rule. As such, the US Army has adapted its standardized BDAR doctrine to fit the current threats associated with the ongoing OEF/OIF conflicts. By continuously re-evaluating the tactical situation and technical capabilities, the warfighter is constantly updated with more capability, equipment, technology and support to accomplish the BDAR mission far more effectively to keep the pressure on the enemy. The US Army's BDAR capability is a successful demonstration of forward thinking for warfighting in the twenty-first century.



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